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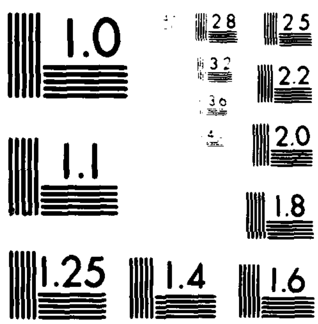

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This report summarizes the effort and results of an extensive study of the mesoscale wind field. In particular, the temporal and spatial variability of the wind in the first five kilometers of the atmosphere was examined in terms of power law relationships.

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12

MESOSCALE VARIABILITY OF THE ATMOSPHERIC WIND FIELD BELOW 5 KM

by

W. H. JASPERSON

FINAL REPORT
ON
CONTRACT DAAG29-76-C-0010
FOR
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RESEARCH TRIANGLE PARK, NC 27709

MARCH 1981

I. INTRODUCTION

Interest in mesoscale meteorological phenomena has been increasing for the past several years. Among the motivating factors for this interest is the fact that large-scale numerical weather prediction has developed to an advanced stage. Further improvements in numerical prediction will come about with advances in the understanding and proper parameterization of smaller scale phenomena such as the energy exchanges at the earth's surface and energy distribution and transfer among various scales of atmospheric motion.

Van der Hoven (1957) has shown that there exists a "mesoscale gap" in the energy spectrum of surface wind data. However, by examining composite aircraft data and serial radiosonde ascents, Vinnichenko (1970) has concluded that more mesoscale energy exists in the free atmosphere than near the surface of the earth. Indeed, Mantis (1963) in a study of constant level balloon trajectories taken near 30,000 feet shows that there is considerably more energy at periods of 30 minutes and longer than there is at periods of a few minutes. Panofsky (1969) lists the presence of quasi-horizontal mesoscale structures along with the related phenomena of convection cells and turbulence produced by vertical wind shear as being three types of subsynoptic motions which may produce important transports of atmospheric properties. The role of mesoscale motion is of fundamental importance to a broad range of atmospheric motion scales.

This report summarizes the effort and results of an extensive study of the mesoscale wind field. In particular, the temporal and spatial variability of the wind in the first five kilometers of the atmosphere was examined in terms of power law relationships.

II. DATA

The METRAC^{TM} positioning system, developed by Control Data Corporation, was used to obtain accurate wind profiles at a field site near St. Cloud, Minnesota. This system operates by measuring the frequency difference between pairs of receivers of a balloon-borne sonde. The accuracy in positioning the sonde is determined by the sonde frequency and the geometrical distribution of the receivers. For the data collected during the project, the positioning error in three dimensional space was less than 1 meter. A more complete description of the system and its capabilities can be found in Gage and Jasperson (1974).

During the course of this project, 26 experiments ranging in length from 2 to 23 hours were conducted. Table 1 presents the data summary. Phase I of the project consisted of experiments 1 - 10. Overinflated 100 g pilot balloons were launched at 30 minute intervals and nominally tracked to heights of 5 km. For Phase II of the project, a second METRAC system was installed so that two balloons could be tracked simultaneously. Experiments 11 - 14 and 26 were conducted by alternating the two tracking systems and tracking balloons launched 10 and 15 minutes apart. Experiments 15 - 25 were conducted by tracking balloons launched simultaneously from spatially separated launch points. Three launch point separations of 20 m, 4.415 km and 20.910 km were used. For each experiment, balloons were launched from a given pair of launch points at 30 minute intervals. During the second phase, a defective batch of balloons was received and many of these balloons burst prematurely. In all, however, 87% of the balloons were tracked to at least 4 km and 67% were tracked to at least 5 km altitude.

For each balloon flight, mean winds were computed over 100 m layers with the value assigned to the midpoint. Both vector and component winds were derived. Component winds consisted of u (W-E) and v (S-N) winds as well as longitudinal and transverse winds. The longitudinal and transverse wind components were computed with respect to the mean wind direction for each level over the period of each experiment.

The wind profiles collected during this project were characterized by a high degree of accuracy and vertical resolution. Experiments were conducted in a variety of weather conditions, and per flight costs were relatively small. Balloon launches were made at

TABLE 1 DATA SUMMARY

EXP.	NUMBER OF FLIGHTS	DATE(S)	FIRST LAUNCH (LST)	LAST LAUNCH (LST)	DURATION (hrs.)	MIN. TIME SEPARATION (min.)	SPACE SEPARATION (km)
1	14	3/31/76	1330	2000	7	30	0
2	16	1/19/77	0700	1430	8	30	0
3	23	1/25/77	0730	1900	12	30	0
4	12	5/10/77	0500	1300	8½	30	0
5	24	6/9/77	0430	1930	15½	30	0
6	5	6/29/77	0930	1130	2½	30	0
7	41	7/21-22/77	0900	0700	22½	30	0
8	45	12/14-15/77	1430	1300	23	30	0
9	37	4/11-12/78	1000	0830	23	30	0
10	31	5/3-4/78	0900	0030	16	30	0
11	16	7/27/78	1145	1615	5	15	0
12	39	8/15/78	1000	1945	10	15	0
13	20	8/16/78	0745	1230	5	15	0
14	20	8/28/78	0810	1300	5½	10	0
15	5	9/19/78	1730	1900	2	30	20.910
16	35	9/20/78	0700	1800	11½	30	20.910
17	24	9/21/78	0700	1430	8	30	20.910
18	29	10/2/78	1200	1930	8	30	4.415
19	47	10/3/78	0700	1900	12½	30	4.415
20	49	10/4/78	0700	1900	12½	30	4.415
21	40	10/5/78	0700	1830	12	30	4.415
22	19	10/6/78	0730	1200	5	30	4.415
23	26	10/16/78	1100	1800	7½	30	0.020
24	29	10/17/78	0800	1730	12	30	4.415
25	26	10/18/78	0730	1330	6½	30	0.020
26	17	10/31/78	1100	1640	6	10	0

fixed time intervals. None of these factors considered individually distinguishes the data collected during this project from data taken for certain other experiments. However, when all of the factors are considered together, the project provided a unique set of wind profile data.

III. *SUMMARY OF RESULTS*

One of the most fundamental results of the study concerned the accuracy of wind profiles as measured by balloon/sonde systems. The wind profiles were made using ordinary 100 g pilot balloons, overinflated to obtain an ascent rate of at least 5 m/s. Balloons of this size and ascent rate operate in the supercritical Reynolds number regime and tend to undergo random oscillations as they rise. Experiments 23 and 25 provided data for pairs of balloons launched simultaneously from points 20 m apart and tracked independently. A comparison of the resulting winds provided an estimate for the wind measurement accuracy. This difference or "error" included ground system error, balloon/sonde system error plus any true variability that exists in the wind field on the scale of a few hundred meters and a few tens of seconds, the space and time separation of the balloons at 5 km altitude. This error, therefore, represents an upper bound error in the measurement of 100 m mean winds. Theoretical simulations showed that the ground system errors should be less than 0.1 m/s. The positioning error is independent of wind speed. Furthermore, for the balloons tracked in these experiments, the ground system error is small enough with respect to the errors introduced by the balloon/sonde system that the total error is effectively independent of geometrical position.

The rms upper bound errors including all factors discussed above were found experimentally to be about 0.475 m/s for component and total wind speed and 0.700 m/s for the magnitude of the vector wind speed for the 100 m thick layers. Wind direction errors are directly dependent upon wind speed and were less than 3^{o} at 10 m/s and about $.5^{o}$ at 50 m/s.

A goal in wind variability research has been to define the dependence of variability upon a time or space lag. Because the accuracy of measurements required for variability studies increases as the time or space scale decreases, much of the past variability work has examined synoptic scale variability. However, there have been several studies over periods as short as an hour. Ellsaesser (1960) presents a comprehensive review of variability data.

Many time variability researchers have chosen a power law exponent of 1/2, and this value is most often referenced in the literature for the time variability dependence. Ellsaesser (1969), however, has examined many of these data and has found that a 1/3 power law is more consistent with the data for time scales up to several hours. A 1/3 power law dependence is predicted for three dimensional isotropic turbulence satisfying the Kolmogoroff inertial subrange. While the three dimensional inertial range may be difficult to justify at scales exceeding 10 km, Gage (1979) has pointed out that a 1/3 power law is also consistent for the two dimensional reverse cascading energy inertial range. If, in fact, a two dimensional reverse cascading process is present on the mesoscale, there are obvious dynamical consequences.

Time variability as a function of lag was computed for each experiment and each 100 m layer. These variabilities were then averaged together over 1 km intervals and over the entire 5 km interval to provide average estimates of the variabilities. Substantial variability differences were present among different experiments. In order to try and explain the experiment to experiment differences, the experimental days were subjectively divided into anticyclonic and cyclonic catagories on the basis of the synoptic weather patterns. Cyclonic days typically had frontal passages or strong cyclonic curvature in the surface isobars. Anticyclonic days were defined to have anticyclonic curvature in the surface isobars. A few experiments could not be clearly classified as either anticyclonic or cyclonic and were therefore eliminated from this analysis.

Time variabilities for all the anticyclonic days were averaged together over each 1 km interval and over the entire 5 km layer with the following results. The variability, plotted as a function of time lag on a log-log graph, showed a slight dependence on height between 1 and 5 km with increased variability related to increased height. This dependence is most likely a reflection of the positive correlation between variability and wind speed which has been observed before. The slope of the wind component and vector wind variability curves showed a very nearly 1/3 power law relationship for all of the heights and for time lags out to 5 hours, the last lag computed.

Time variabilities for the cyclonic days were similarly averaged together. The slope of the variability curve for the longitudinal wind component again showed a 1/3 power law relationship. However, the variability curve for both the transverse and vector wind yielded a slope of very nearly 1/2. The large values of the variability and large slope for the transverse wind are due to the sharp changes in the wind direction that occurred during the frontal passages.

Inaccuracy in wind measurement always causes the computed variability to be overestimated. This effect is largest for short time lags when the variability is small. The result of wind measurement error on variability curves is an underestimation of their slope on a log-log plot. Using upper bound errors described earlier, the effect of these errors on the slope of the variability curves is less than the differences between experiments.

Space variability was examined for experiments 15 - 25. Attempts to identify specific features such as waves in the wind field as they progressed over spatially separated launch points were not successful. Because experiments with different separations were run on different days, power law relationships for spatial variability were not computed. However, statistical relationships between time variability and space variability could be examined.

Each space variability experiment consisted of sequences of balloon flights from two launch points separated by either 20 m, 4.415 km or 20.910 km. From these data three different vector wind variabilities were calculated:

1. The space variability between pairs of simultaneously launched balloons
2. The time variability at each launch point
3. The time-space variability between pairs of balloons launched at separate points and lagged in time

The data for each spatial separation (number 1, above) were averaged together for the following summary. The 20 m vector wind variability was 0.99 m/s which was the number used to compute the upper bound vector wind error of 0.700 m/s. For the 4.415 km separation, the variability was 1.741 m/s, and for the 20.910 km separation, it was 2.446 m/s. Table 2 gives the true vector variability for each of the three spatial separations as a function of the true rms error. The upper bound error of 0.700 m/s gives the lowest true variability. The table illustrates the sensitivity of the variability to error, particularly for small variabilities.

TABLE 2. True variability as a function of spatial separation and assumed rms measurement error.

rms error (m/s)	0.00	0.50	0.60	0.70
separation (km)				
0.020	0.990	0.700	0.510	0.000
4.415	1.741	1.591	1.520	1.429
20.910	2.446	2.342	2.294	2.234

A comparison of the space-time variability with the time variability (2 and 3, above) showed no detectable variability difference for the 20 m separation. However, there were detectable differences between the two for the 4.415 km separation out to 60 minutes in time lag and differences for the 20.910 km separation out to about 90 minutes in time lag. These are the times at which differences in the statistics computed for each of the spatially separated launch points become small relative to the increasing time variability.

A time variability and space variability equivalence can be found by comparing the time variability calculated as a function of time lag with the space variability (1 and 2, above). By extrapolating the time variability power law curves to times shorter than 30 minutes, a time and space variability equivalence for the 4.415 km separation was found to be about 15 minutes. For the 20.910 km separation, the analogous time and space variability equivalence was found to be about 100 minutes.

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V. SCIENTIFIC PERSONNEL SUPPORTED ON PROJECT

W. H. Jasperson (1976 - 1980)

K. S. Gage (1976)

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